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Waste to Resource Process Chain Strategies for Global Manufacturers

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Abstract

In order for suppliers to stay competitive in the global market, innovative and resource efficient process chains need to be a part of their manufacturing strategies. In this study the effect of different waste to resource process chain strategies were evaluated. The objective was to transform the material waste from a cutting process into a resource. The metal chips were collected and the effect of lubrication and briquette forming strategies on value were investigated. The effects on cost and quality were evaluated and the influence on factory planning assessed. The value of the briquette increased with a reduction in lubricant during the cutting process and by compacting the metal chips.

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Keywords: Waste; Resource; Recycling; Aluminium; Process Chains; Sustainability; Manufacturing

1. Introduction and Background

In 1966, Boulding [1] described the current state of the economy as a transition between the so called ‘cowboy economy’ of the late 19th century and the ‘spaceman economy’ of the future, which we will reach by the latter end of the 21st century. In the 19th century, the economy was driven by exploitative tendencies, where resources were readily available for the taking. Consumption and production in this type of economy was seen as a positive thing and success was measured by the amount of throughput in the system. This mindset largely prevails even today in most parts of the world. In contrast, the ‘spaceman economy’ is used by Boulding to explain a system which is aimed at minimising throughput. The resources already in the system needs to be reused and maintained in the current system. These terms are closely linked with modern buzzwords such as sustainability. Environmental and economic incentives are forcing manufacturers to think with this mindset and reconsider the process they use to manufacture goods. One environmental concern is the sheer volume of earth that needs to be removed to produce small quantities of metals. Table 1 shows the metal content in ore for the various metals [2]. Not only is the demand for metal growing, but metal ore is degrading in quality as well. The quality of copper ore has fallen from about 10% in the 19th century to 0.47% in 2014 [2,3].

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Table 1: Metal Content of Ores [2]

Metal	Metal Content (%)
Aluminium	19
Chromium	10
Copper	0.4
Gold	0.0005
Iron	52
Lead	6.5
Manganese	33
Nickel	0.7
Platinum	0.0005
Uranium	0.002
Zinc	3.2

Waste to resource processes allow manufacturers to close the manufacturing cycle. The general, simplified product life cycle is seen in Figure 1 [4]. The goal of this waste to resource research is to achieve as close as possible to 100% efficiency in this cycle, thereby reusing as much metal as possible that is available in the current system. This can be achieved by minimising as much residues as possible. In this paper, a case study is done at Hansens Engineering. The facility produces aluminium parts for use in the automotive industry. Machining of these parts create a considerable amount of scrap, because of the high volumes they produce, the in-house recycling process of which is analysed.

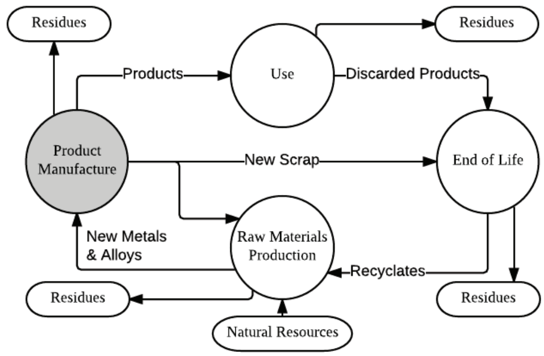

Figure 1: Simplified Metal Material Flow. Adapted from [4]

The process analysed is thus that of the 'Product Manufacture' circle in Figure 1. Out of this process flows products, new scrap and residues. In this paper, as is done by the engineers at Hansens, this new scrap is seen as a product on its own and not a waste product. Residues arise from this operation, which is everything that is not recycled and directly disposed of. These are minimised by implementing manufacturing strategies such as minimum quantity lubrication (MQL) and an automatic briquetting system, ensuring a greater amount of swarf (new scrap) can be recovered at a greater economic value. This is a prime example of a waste to resource process, where swarf is used to produce a product, simultaneously with the production of the machined component. Primarily, financial resources are compared, with discussions on the implications on environmental and human resources.

2. Waste to Resource Strategies

Lubrication and swarf processing systems are assessed as waste to resource strategies. MQL is a lubrication technique which implements very small amounts of lubrication fluid. This results in a near dry manufacturing environment. Hansens Engineering provides the ideal scenario to assess the implications of different waste to resource strategies, because they have implemented the MQL and briquetting systems in their manufacturing processes, but still have older, conventional flood lubrication installed in older processes. Swarf is also sold in briquette and loose form, which is another strategy which can be assessed. This creates a platform where in-house recycling for different scenarios can be compared. While the waste to resource strategies they have implemented in their current machines are very efficient, the company is continually striving to improve. Current projects include a prototype machine with built-in swarf briquetting system, essentially producing two sellable products simultaneously.

2.1 Minimum Quantity Lubrication (MQL)

MQL is an alternative lubrication method to traditional flood cooling. It is otherwise known as micro lubrication or near-dry machining. The method is used to cool and lubricate the cutting tool and workpiece interface in machining. As the name implies, the method is concerned with using the minimum amount of cutting fluid, resulting in cost savings in the purchase and disposal of these fluids. Pressurised air is used to spray micro-scale droplets of cutting fluid onto the contact area. The implementation of MQL brings many advantages over traditional flood cooling. In MQL, a more environmentally friendly vegetable oil or synthetic ester oil is used instead of the mineral oil used in flood lubrication, because very good lubrication properties are required [5]. Not only does MQL have an economic advantage because of the reduced usage of coolant, but it has been shown to result in reduced tool wear compared to both dry and flood lubricated methods [6]. Unlike flood cooling, MQL is a form of consumption lubrication, as the majority of the fluid evaporates on contact when applied [7]. The resulting system has a near dry work piece and produces swarf which requires no further drying or washing as the cutting fluid is evaporated. Since the amount of oil on the swarf is less than 1%, it can be introduced directly into the furnace when remelting, without any concerns over excessive smoke creation or melt losses [8]. This also means that there are no additional costs incurred with the disposal of cutting fluid, which is required in flood cooling. The vapour produced by the MQL operation does however, pose some health risks. MQL cooling generates a large amount of mist compared to flood cooling, which needs to be properly ventilated [7].

2.2 Briquetting

The large surface area-to-volume ratio of machine swarf makes it very prone to oxidation during melting. This means that a low amount of metal is recovered, while high energy input is required. Briquetting the loose swarf helps to reduce this surface area-to-volume ration and also assists in squeezing out any remaining lubrication fluid out of the feed. Loose swarf is typically compacted under a pressure of about 30MPa [8]. There is a potential for recycling flood lubrication cutting fluids using briquetting technologies. This helps reduce the amount of smoke and gasses generated in the melting process while also reducing fumes produced from oxidation of smaller pieces of swarf. Some research has shown that there is no difference in the density of the briquette achievable by dry and wet swarf [9]. Loose swarf is also difficult to handle and transport. Loose swarf has a density of about 0.25g/cm^3, while briquetted swarf has a density of roughly 2 g/cm^3 [10]. Briquettes are uniform in size and thus easily transportable. Because briquettes are much denser, a higher quantity can be transported at a time when compared to loose swarf, resulting in more efficient transportation.

3. Research Methodology

The research methodology followed is seen in Figure 2. A basic understanding of strategies affecting the quality of swarf, with regards to lubrication and packing density is done in the Waste to Resource Strategies section to gain an understanding of the MQL and briquetting technologies. These process waste handling strategies were then seen in action by conducting a case study at Hansens Engineering. This involved comparing traditional strategies with current, more efficient, waste to resource strategies and then a possible near future improved process. These strategies were implemented on three different machine setups. They were then evaluated and compared in terms of capital investment costs, scrap value creation, lubrication costs and environmental impact.

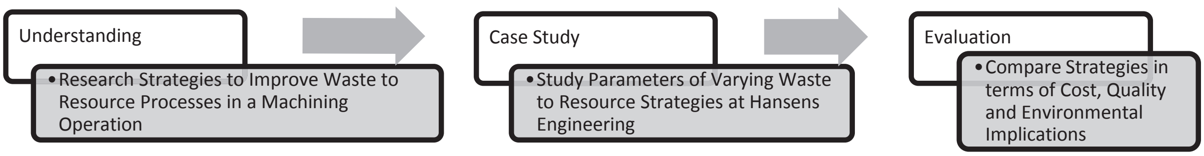

Figure 2: Research Methodology Followed

4. Case Study

Three cases are evaluated, each with differing waste management strategies. These strategies are:

- Conventional Machine Setup (Daewoo 2)
- Retrofitting MQL lubrication on machine with centralised briquetting system (Turning Cell 3)
- New scathing machine design with built-in briquetting system

All three machine setups are analysed assuming they are producing product V30-A02 (), which is used in shock damper components for the automotive industry.

Figure 3: Picture of Component V30-A02

The component volume and blank volume were calculated from CAD models. The percentage swarf produced by each part could then be calculated by subtracting the two. These values are shown in Table 2. The density of aluminium alloy ENAW 6082-T6 is 2.7 g/cm^3, and by utilising this, the weight of swarf per part V30-A02 can be calculated.

Table 2: Blank, Component and Scrap Volumes for Part V30-A02

Description	Volume (mm^3)
Blank	19957.608
Component	13990.282
Swarf Per Part	5967.326

4.1 Conventional Machine Setup

The conventional machine setup analysed is the Daewoo 2 setup, an operation with a profiling, drilling, chamfering and parting operation. In the conventional machine setup, lubrication is applied to the part and tool in the form of flood cooling. Once the machining operations are completed, wet swarf is produced. This wet swarf is sold to other companies, where it has to undergo a degreasing operation before it can be melted. Although it is referred to as wet swarf it is not completely wet. In the past, oily swarf was added to the melting process without any cleaning operations, but the smoke resulting from the burn would have adverse effects on the factory workers [8]. A system is implemented in the machine which removes the swarf at an incline, causing the majority of the lubrication fluid to stay in circulation in the setup. This results in relatively dry swarf, but not dry enough to compress to briquettes. A drying step thus needs to be implemented if one has the desire to process the wet swarf further in-house, which incurs additional process time and thus a slower throughput. There is a possibility that pockets of lubrication fluid can form in the compressed briquette if compressed when wet, this may cause damage to the smelter when introduced into a smelting operation. This additional required process step is reflected in the buying price of loose wet swarf. Lubrication fluid is reused in the operation, but needs to be disposed of after a while and requires some upkeep. On a weekly basis the concentration of lubrication fluid needs to be tested by a reflectometer. A lab analysis is done on a monthly basis to check the concentration and pH levels, din corrosion and percentage tramp oil. These services are provided at no extra cost to Hansens. Once a year, flood coolant is treated with acticide and system cleaner.

4.2 Retrofitting MQL and Briquetting System

Turning cell 3 has 5 machines. The process for each is similar, even though the parts they produce are marginally different. A blank is fed in the machine by 32mm bar with a 13mm centre hole and clamped with a hydraulic draw. The blank starts to rotate and a cutting tool faces and profiles to part. Shortly after this process, a drill creates the centre hole. A part catcher substitutes the position of the drill and a parting tool separates the part from the remainder of the bar. The part drops onto the part catcher once separated and out, where a Motoman robot grabs it and places it on a pin. The part goes through an air gauge inspection to verify the dimensions of the centre hole and is fed into a box for electronic visual inspection thereafter. The part is sent down a bottom shoot if any of these inspections are failed. If it passes both inspections, a back chamfer is added. The part undergoes further downstream washing operations to ensure cleanliness to finalise the product. This turning cell was retrofitted with a MQL setup. An image of the MQL setup on a turning machine is seen in Figure 4. The three lubrication feed pipes can be seen entering the machine, one for each contact point in the operation (profiling, drilling and parting).

Figure 4: MQL System Implemented in Turning Cell 3

As seen in Figure 5, a ventilation system is installed in the machine cell as well. This is used to minimise the effect of mist created by the MQL setup and minimise health risks.

Figure 5: Ventilation System Installed to Reduce MQL Mist Health Risks

Implementing MQL is thus effective in creating a more resource efficient process chain in three ways. Firstly, with the reduced cost of purchasing lubrication fluid as the volume required is so little, secondly because there is no disposal cost required of cutting fluid and finally, because it removes the requirement for further processing of scrap before it can be briquetted. The loose swarf is collected under the machine and periodically moved by hand to a central briquetting machine, which is used to briquette the entire machine cell's scrap. The briquetting machine is shown in Figure 6 without the top shredder. The shredder reduces the size of the machine swarf, so they can be compacted tighter.

Figure 6: Loose scrap fed into briquetting machine

The resulting compacts can be seen in Figure 7. They are about 5cm in diameter and vary in length. This is fairly small, with the standard diameters in industry being between 12 and 50 cm [8]. The collected briquettes, once they moved up the ramp at the end of the briquetting machine are shown in Figure 7. These briquettes are weighed in real time and the weight of the batch is displayed on the wall next to the briquetting machine.

Figure 7: Aluminium briquettes produced

Figure 8: Collected scrap briquettes

Implementing this briquetting system results in a 70% increase in swarf value. Retrofitting these systems onto an existing machine does bring undeniable benefit with regards to the value gained from the produced waste, but can be an expensive exercise.

4.3 Built in Waste to Resource System

The current state-of-the-art project being developed at Hansens involves a prototype machine which has a built in system for shredding and briquetting machine swarf. Once implemented, these machines will be capable of producing a significantly improved amount of briquetted swarf, because of the reduced cycle time of the machine. Since the briquetting system is implemented in the machine itself, there is no need to transport loose swarf to a centralised position as is currently done. This will result in greater ease with regards to the handling of swarf and possibly reduced losses during the transportation thereof, moving ever closer to a 100% efficient material cycle. While there is a MQL system installed on the prototype machine, the engineers at Granroth are looking at implementing dry machining in the fully functional models. With reduced cycle time, resulting in increased scrap production, reduced scrap handling, because built-in briquetter and no lubrication costs, these machines will have reduced process residues to a very low amount. The prototype machine will also be available at a cost similar to that of the machines in turning cell 3.

5. Results and Discussion

The quality of scrap is only put into two categories by Hansens, namely loose swarf and briquetted swarf, as this is the only measure that determines the value assigned to it. The briquettes from the processes were analysed to look for possible improvements in packing density. The density of the benchmark briquette, given to Hansens by the manufacturer of was calculated to be 1.99 g/cm^3, consistent with the 2 g/cm^3 industry standard found in the literature. Briquettes from Turning Cell 3 and the new prototype machine was found to be less dense. Their densities were calculated to be around 1.67 g/cm^3 and 1.59 g/cm^3 respectively. Although the buyer will not pay extra if the briquettes were compacted tighter, it may mean that they could fit up to 20% more scrap in a shipment.

Figure 9: Benchmark briquette

Figure 10: Analysing briquette from Turning Cell 3

Contrary to what the literature says, it was found that lubrication costs using flood cooling and MQL are very similar per part. MQL does still provide less effort in terms of treatment as disposal of lubrication fluid and also improved scrap quality. As seen in Figure 11, the lubrication costs for turning cell 3 is marginally higher than that of the Daewoo 2. This is primarily due to its increased throughput rate. Both methods work out to be around 2c per part, and as Turning 3's machines produce more parts per shift, more money is spent on lubrication. With this increase in throughput comes a greater amount of scrap per shift, plus the ability to briquette the swarf. Because of this, the value of swarf produced from Turning Cell 3 is more than double that of the Daewoo 2. This is further improved in the new prototype machine. Because dry cooling may be implemented, no money is spent on coolant and with a further large increase in throughput rate the value of scrap is above R800 per shift, per machine. This from a product which is traditionally seen as waste.

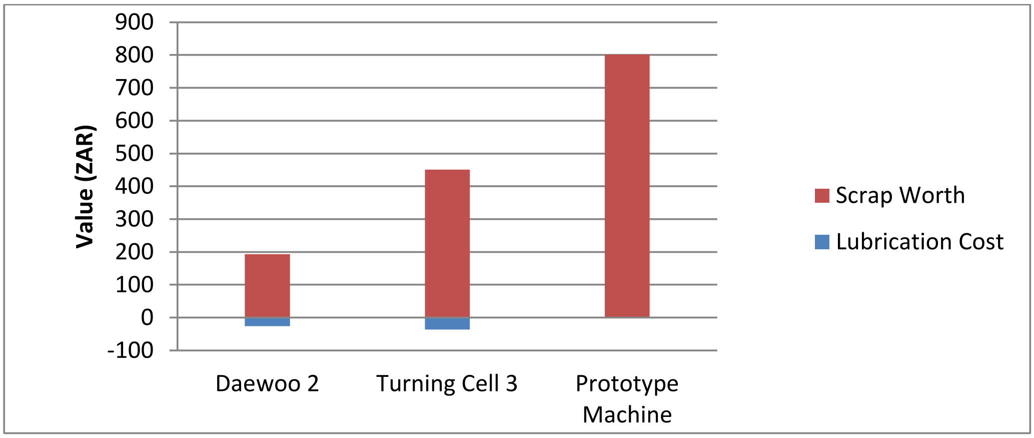

Figure 11: Comparison of different strategies with regards to lubrication cost and scrap value

This improvement in scrap value per shift comes at a cost. When compared to the Daewoo 2, Turning Cell 3's machines have a 149% increase in investment costs and the new prototype machine has a 133% increase in investment costs. The new prototype machines, while also more than double as expensive, are less expensive, as there is no need to retrofit MQL and briquetting systems on them. The new prototype machine will be able to break-even with the increase in price from the Daewoo 2 within a year and a half, with scrap value alone and with the entire machine investment cost within 2 years and 4 months (assuming regular operating times and business days only).

6. Conclusion and Outlook

Hansens have made considerable improvements to reduce the amount of waste in their processes. Waste processing and handling strategies have allowed them to have an edge over their competition. In terms of new scrap handling, Hansens have reached a level which will be difficult to improve on. Thus they are looking to further improve the value of scrap in-house, completing the materials cycle. Instead of new scrap flowing from their process to end of life and raw materials production steps, recycled new scrap can be processed in-house. This will reduce the reliance on raw materials produced from natural resources and their own scrap and reduce residues resulting from their process. If implemented, a true in-house waste to resource process will be realised, where their scrap is turned directly into the raw material required for their process.

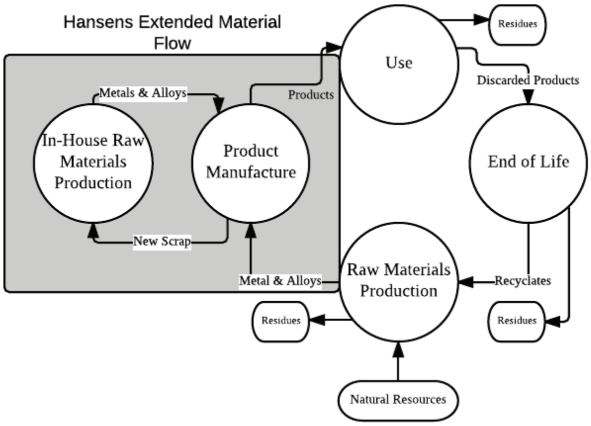

Figure 12: Outlook for In-House recycling

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